

## The Second Catalog of AGNs Detected by the Fermi LAT (2LAC)

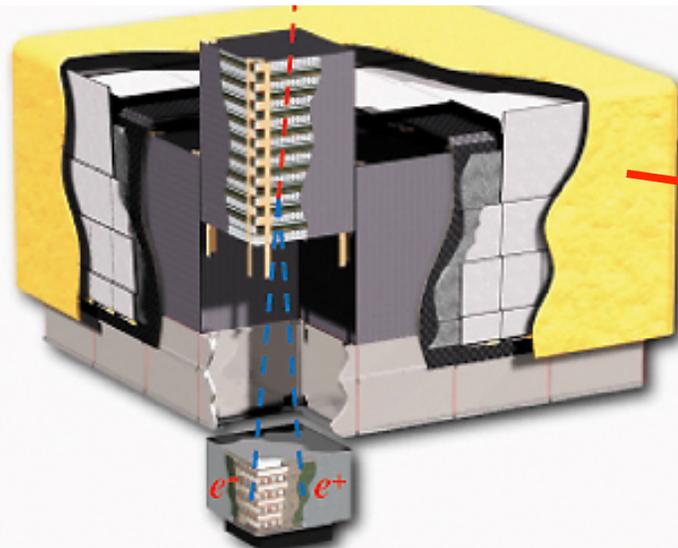
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E. Cavazzuti, S. Cutini, C. D. Dermer, D.  
Gasparrini + C. Ciprini, C. C. Cheung,  
D. Horan, M. Giroletti, S. Larsson,  
A. Reimer  
on behalf of the *Fermi*-LAT collaboration

*Abdo, A. A. et al., accepted by ApJ,  
arXiv:1108.1420*

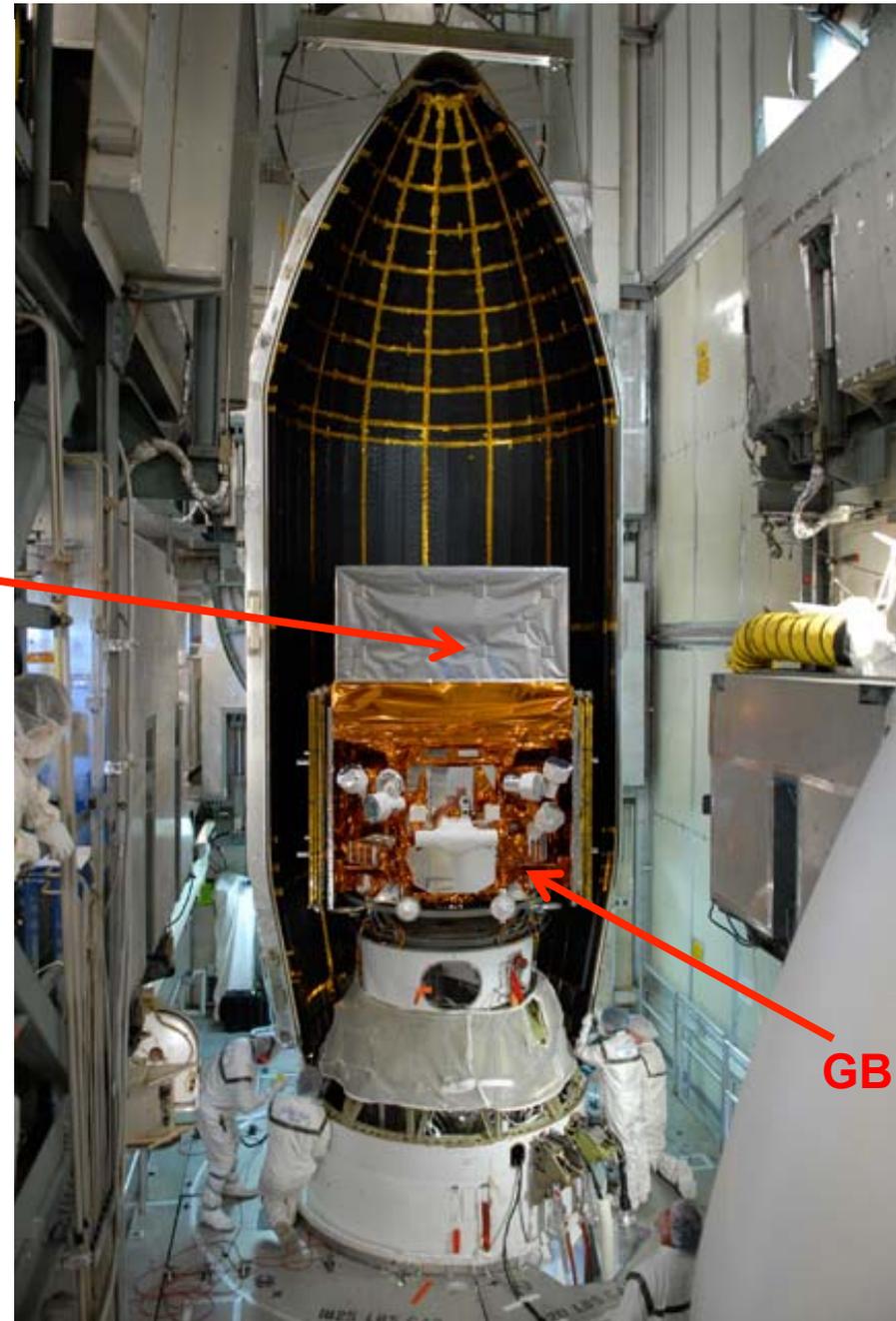
# The Large Area Space Telescope

(launch: June 11, 2008)



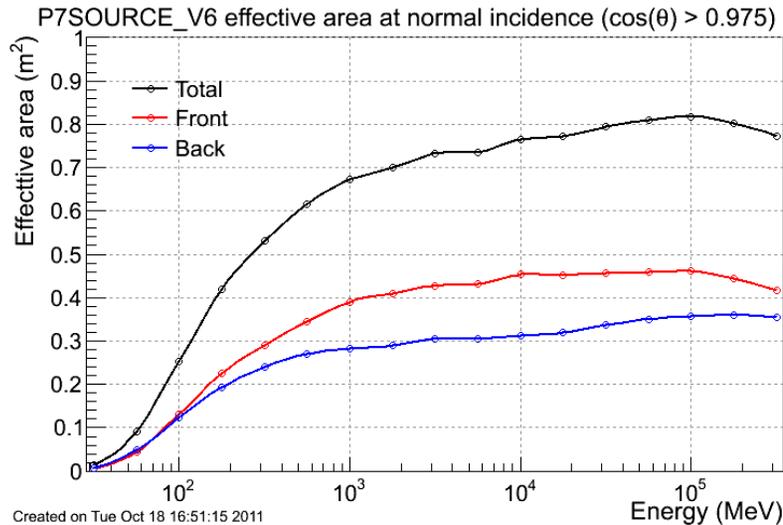
electron-positron pair

LAT images the sky one photon at a time:  $\gamma$ -ray converts in LAT to an electron and a positron ; direction and energy of these particles tell us the direction and energy of the photon

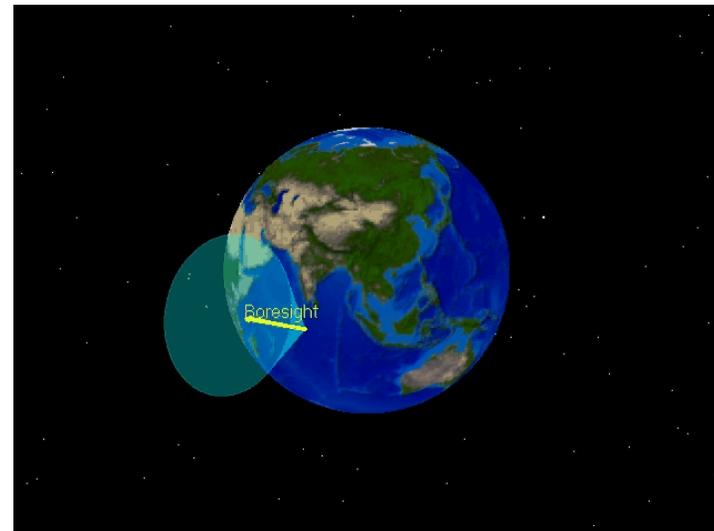
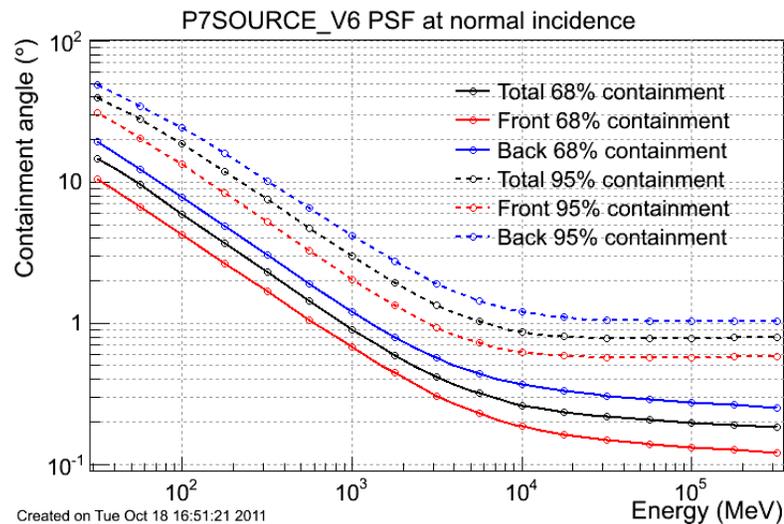


GBM

# LAT performance



- energy range: 20 - 300 GeV
- large FOV: 2.4 sr
- PSF:  $\theta_{68\%} \sim 0.8^\circ$  at 1 GeV
- $A_{\text{eff}} \sim 8000 \text{ cm}^2$  at 1 GeV
- altitude: 565 km
- inclination:  $25.6^\circ$
- orbital period: 91 min
- whole sky covered in 2 orbits in survey mode (rocking angle  $50^\circ$ )



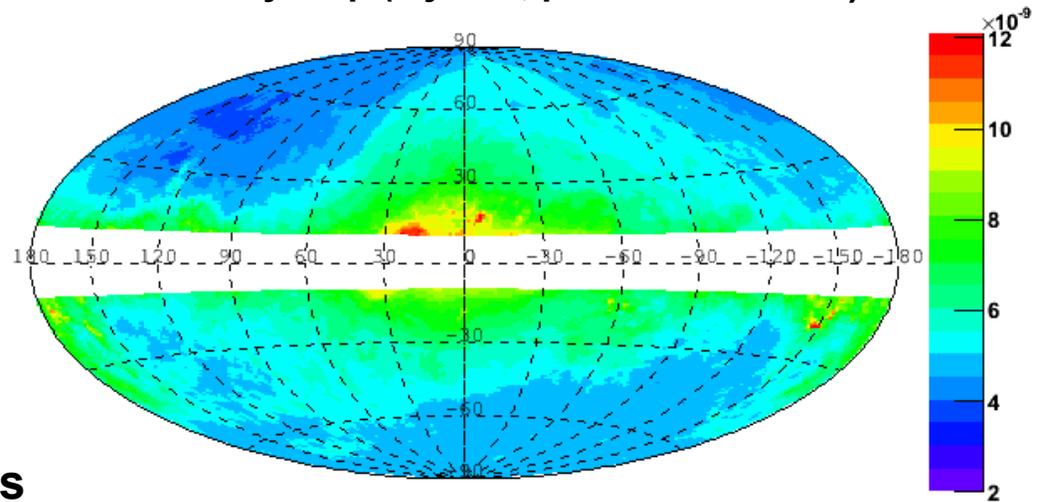
[http://www-glast.slac.stanford.edu/software/IS/glast\\_lat\\_performance.htm](http://www-glast.slac.stanford.edu/software/IS/glast_lat_performance.htm)

# Assets for blazar science



- **unprecedented sensitivity**
- **fairly uniform at high galactic latitude,**
- **sky scanned every 3 hours in survey mode**
- **alerts issued shortly after transient or new flaring sources are detected**

TS=25 sensitivity map (2 years, photon index=2.2)



Flux( $E > 100$  MeV)  $\text{ph cm}^{-2}\text{s}^{-1}$

- **continuous survey allows for source monitoring and variability studies on time scales ranging from months down to a few hours**
- **covers the little-explored 10-100 GeV domain**
  - **new spectral features at high energy discovered**
  - **identification of potential candidates of TeV sources (several discoveries)**

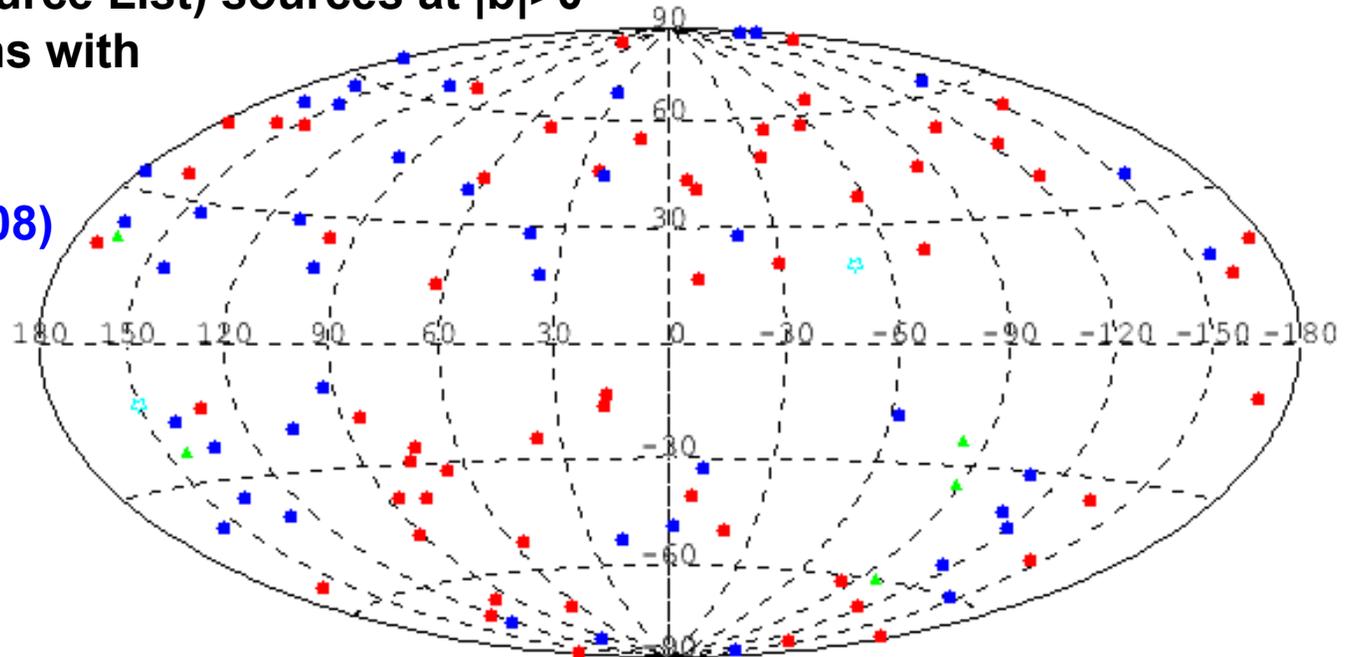
# The LAT Bright AGN Sample (LBAS)



- 3-month dataset,  $TS > 100$
- 132 0FGL (Bright Source List) sources at  $|b| > 0^\circ$
- 116 AGN associations with
  - CGRaBS-CRATES (Healey+ 08)
  - BZCat (Massaro+ 08)

• 106 high-confidence associations:

- 58 FSRQs
- 42 BLLacs (40%)  
10 HSPs
- 2 Radio Galaxies  
Cen A, NGC1275
- 4 of Unknown type



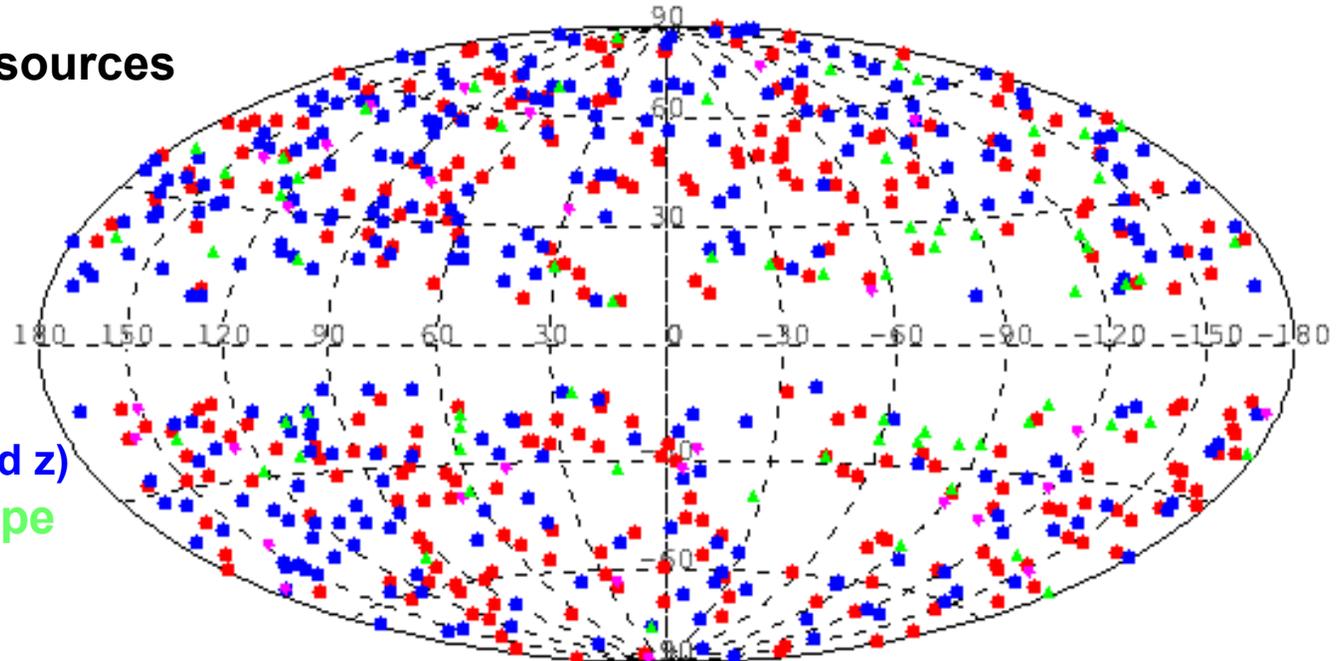
*Abdo A. A. et al. 2009 ApJ 700, 597*

**EGRET sources: only 30%**

# The First LAT AGN catalog (1LAC)



- 11 month data set
- 1079  $TS > 25$ ,  $|b| > 10^\circ$  sources
- 1LAC: 709 sources
- 663 high-confidence ( $P_{\text{assoc}} > 80\%$ ) AGNs
- Censu s :
  - 281 FSRQs
  - 291 BLLacs (~141 with measured  $z$ )
  - 61 of unknown type
  - 30 other AGNs



Differences between Northern Hemisphere and Southern one (FSRQs: 4%, BLLACs: 18 %)

*The First Catalog of Active Galactic Nuclei Detected by the Fermi LAT*

Abdo, A. A. et al. 2010, ApJ, 715, 429

## Differences between 1LAC and 2LAC

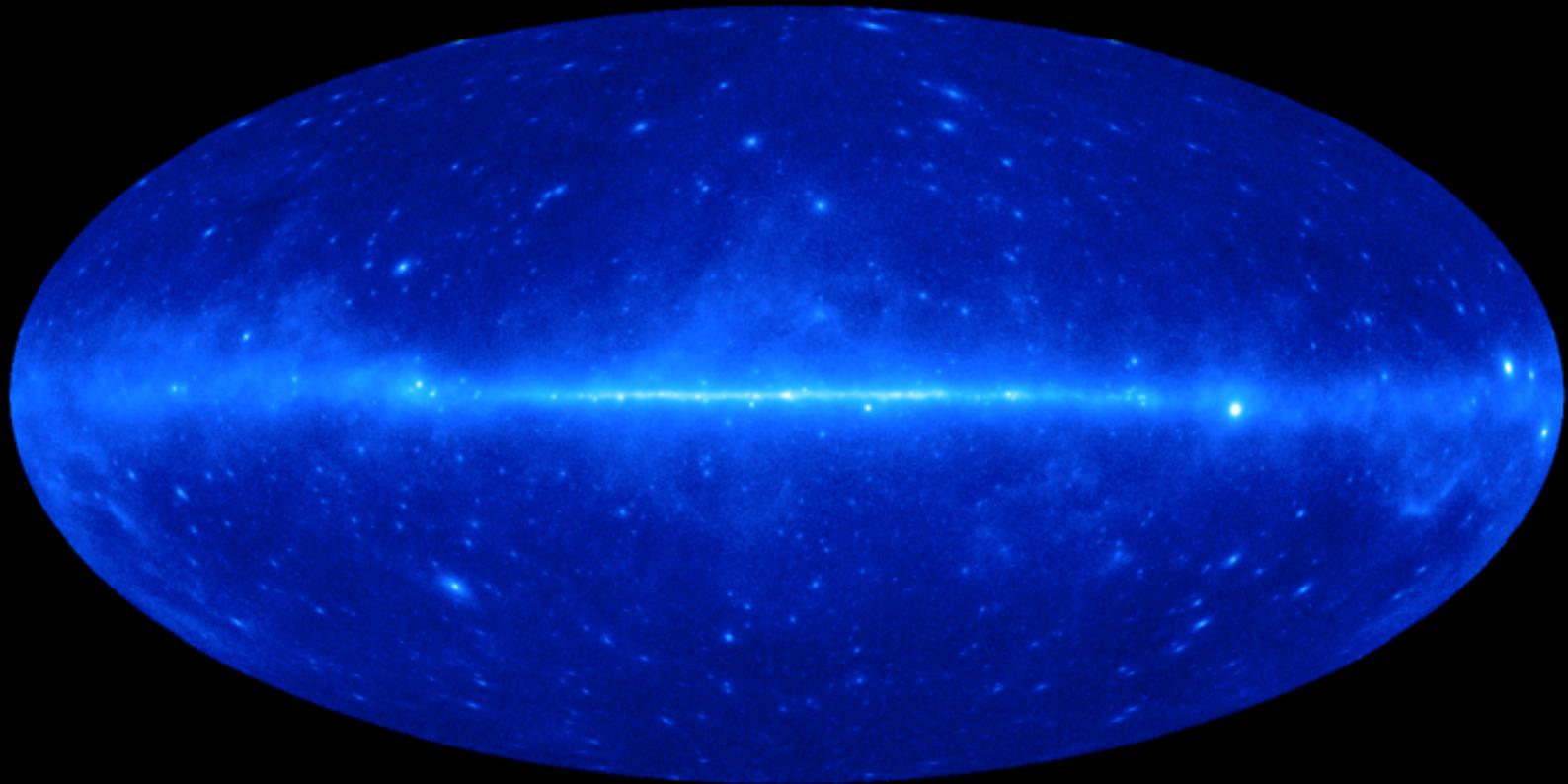


	1LAC/1FGL	2LAC/2FGL
<b>Period</b>	11 m	24 m
<b>Analysis</b>	unbinned	binned
<b>IRFs</b>	P6_V3_DIFFUSE	P7_V6_SOURCE
<b>Association methods</b>	Bayesian	Bayesian Likelihood-Ratio Log N- Log S
<b>Parent catalogs</b>	CRATES/BZCat	Many*
<b>Association**</b>	663/1079 (61%)	991/1319 (75%)
<b>Clean Sample</b>	599	886

\* CRATES, BZCat, NVSS, SUMSS, PMN, ATCA 20 GHz, FRBA, GAPS, CLASS, VCS, RASS

\*\*  $\gamma$ -ray sources/total at  $|b| > 10^\circ$

# Fermi Large Area Telescope 2FGL catalog

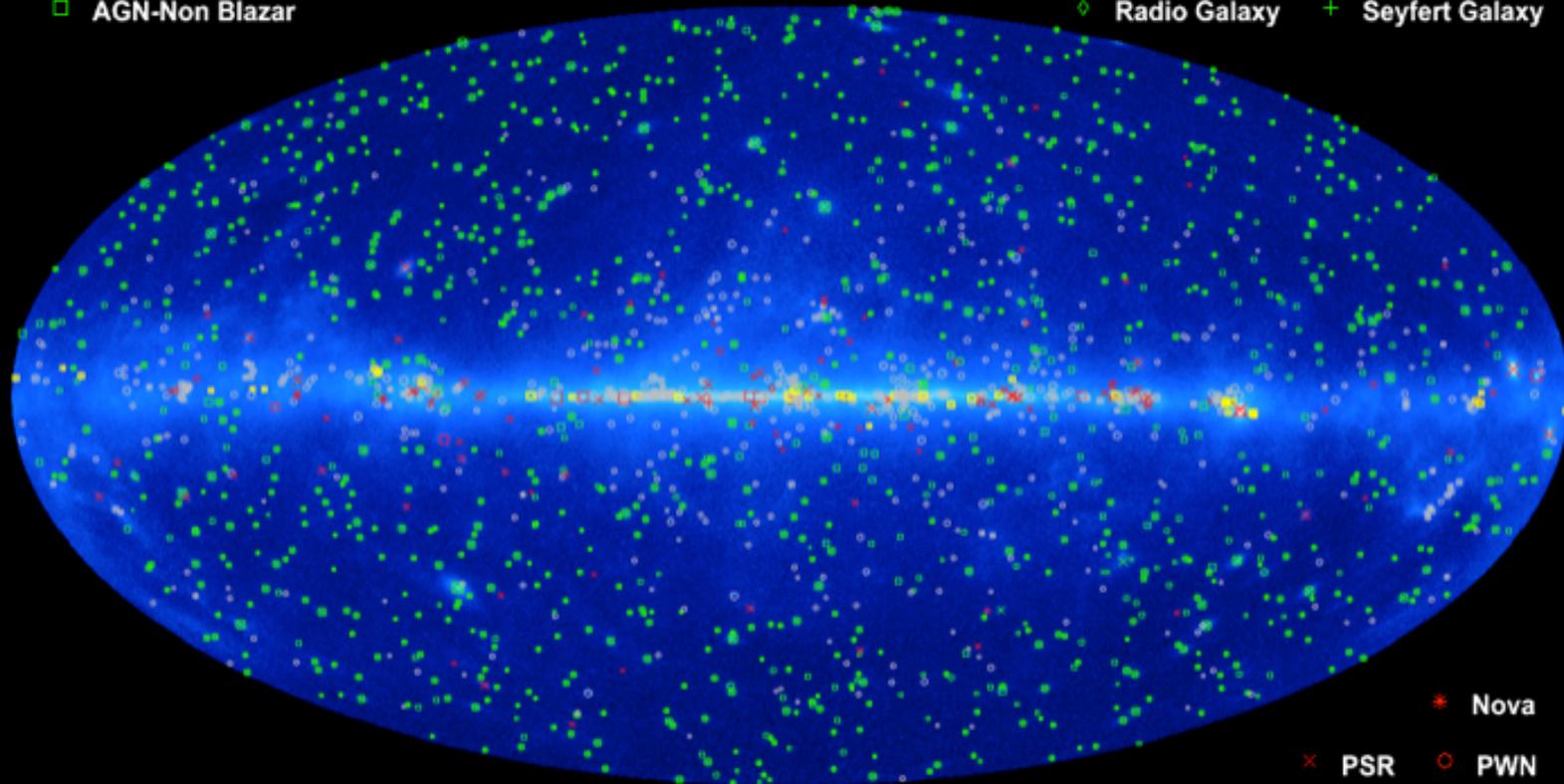


Credit: Fermi Large Area Telescope Collaboration

# Fermi Large Area Telescope 2FGL catalog

○ AGN    ⊗ AGN-Blazar  
□ AGN-Non Blazar

× Galaxy    \* Starburst Galaxy  
◇ Radio Galaxy    + Seyfert Galaxy



○ Unassociated  
□ Possible Association with SNR and PWN

\* Nova  
× PSR    ○ PWN  
◇ PSR w/PWN    □ SNR  
◇ Globular Cluster    + HMB

**1873 sources with  $TS > 25$**

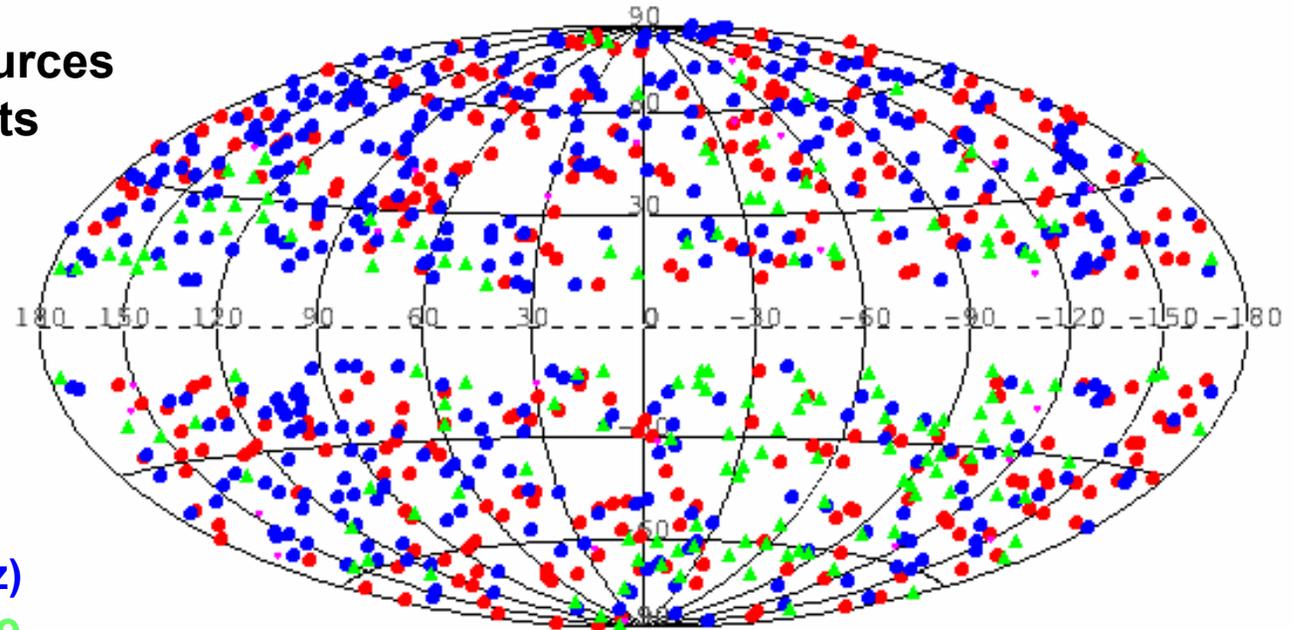
**The Fermi collaboration, submitted to ApJS, arXiv: 1108.1435**

Credit: Fermi Large Area Telescope Collaboration

# The Second LAT AGN catalog (2LAC)



- 24 month data set
- 1319  $TS > 25$ ,  $|b| > 10^\circ$  sources
- 2LAC: 1017 counterparts  
991 sources
- 886 high-confidence ( $P_{\text{assoc}} > 80\%$ ) AGNs in *clean sample*
- Census :
  - 310 FSRQs
  - 395 BLLacs (~45% with measured  $z$ )
  - 157 of unknown type
  - 24 other AGNs



Differences between Northern Hemisphere and Southern one ( 38% BLLACs in Southern Hemisphere)

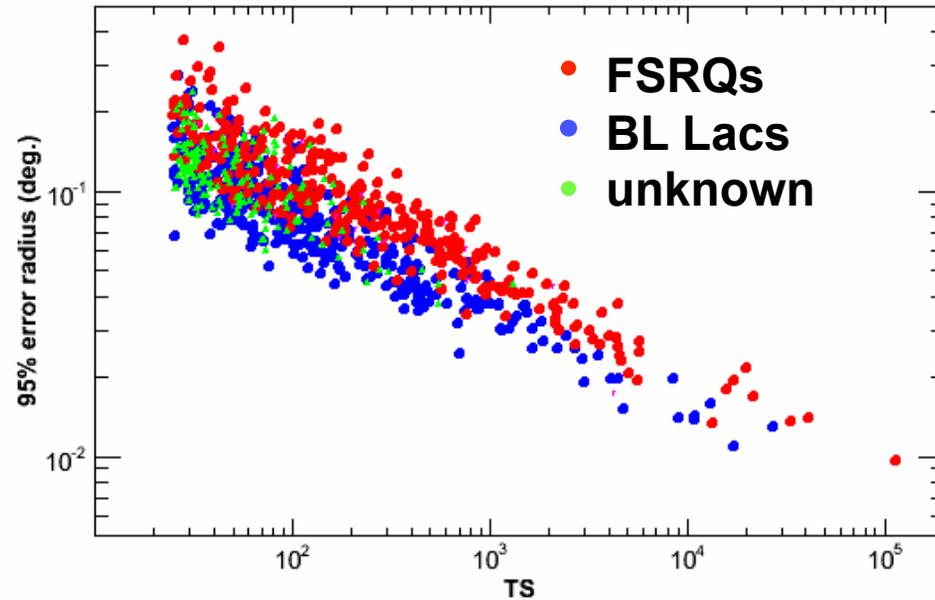
*The Second Catalog of Active Galactic Nuclei Detected by the Fermi LAT*

Abdo, A. A. et al., accepted by ApJ, arXiv:1108.1420

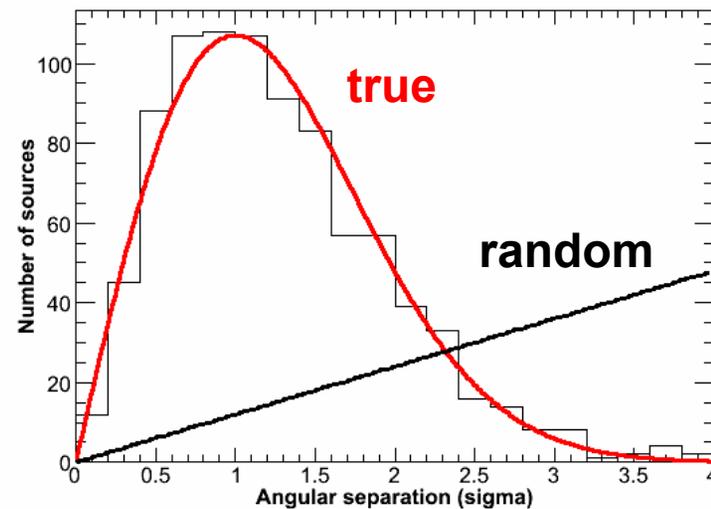
# Angular separation



mean 95% error radius for  
 $|b| > 10^\circ$  1FGL sources:  $0.15^\circ$



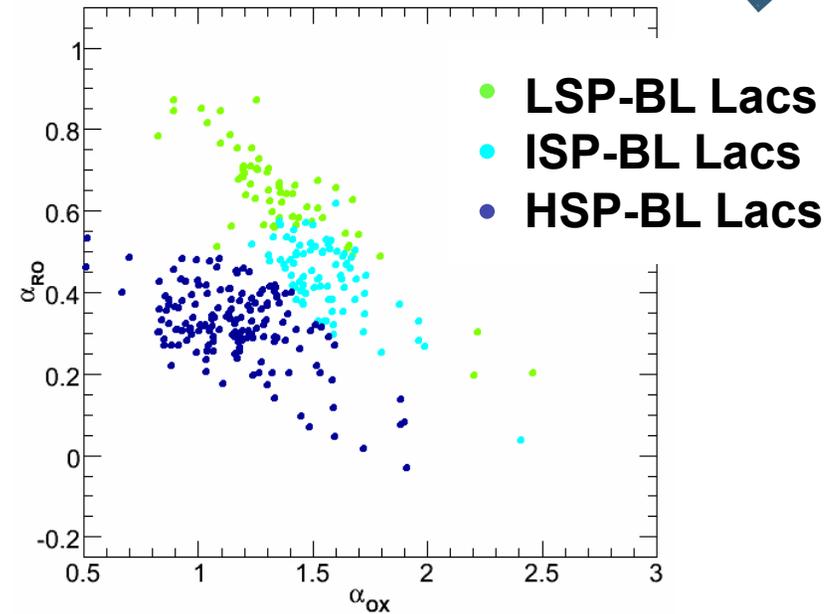
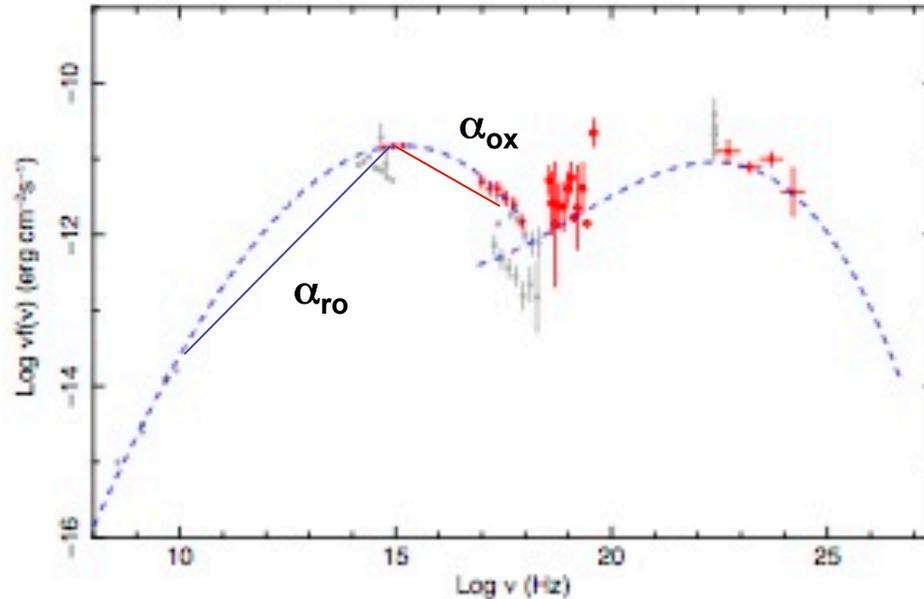
Distance between LAT source and  
AGN counterpart normalized  
to the 68% containment radius  
fraction of false associations  $< 2\%$



# SED-based classification



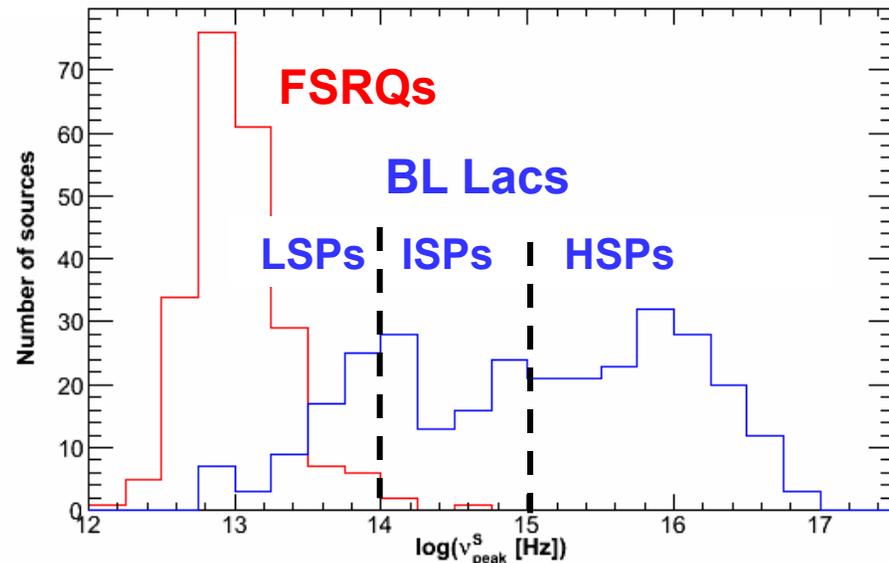
Abdo, A. A. et al. 2010, ApJ, 716, 30



- relation with  $v_{\text{syn}}$  estimated from  $\alpha_{\text{ox}}$ ,  $\alpha_{\text{ro}}$
- subclasses assigned from  $v_{\text{syn}}$   
LSP, ISP, HSP: low-, intermediate-, high-synchrotron peaked blazars, resp.
  - LSP:  $\log(v_{\text{syn}}) < 14$
  - ISP:  $14 < \log(v_{\text{syn}}) < 15$
  - HSP:  $\log(v_{\text{syn}}) > 15$

with  $v_{\text{syn}}$  in Hz

Fermi-Jansky 11/11



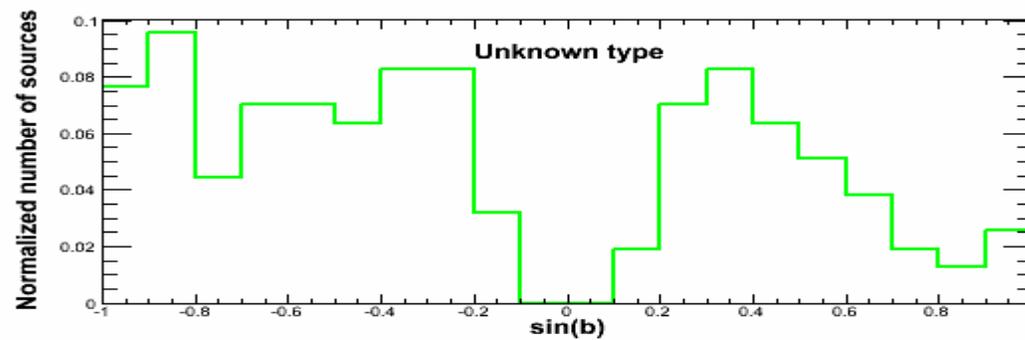
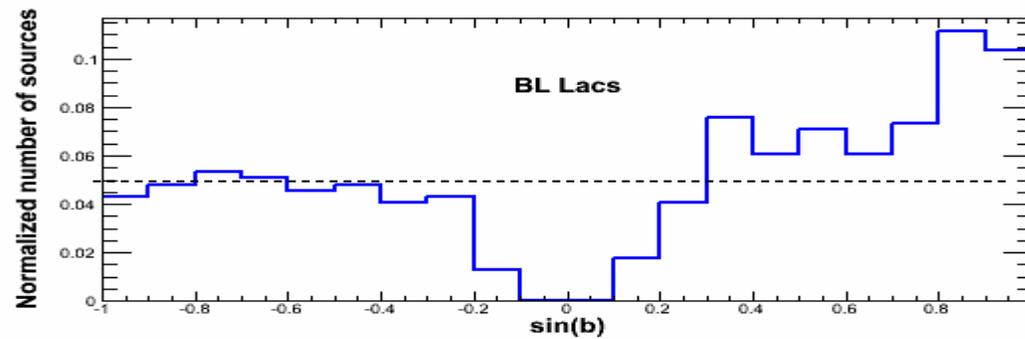
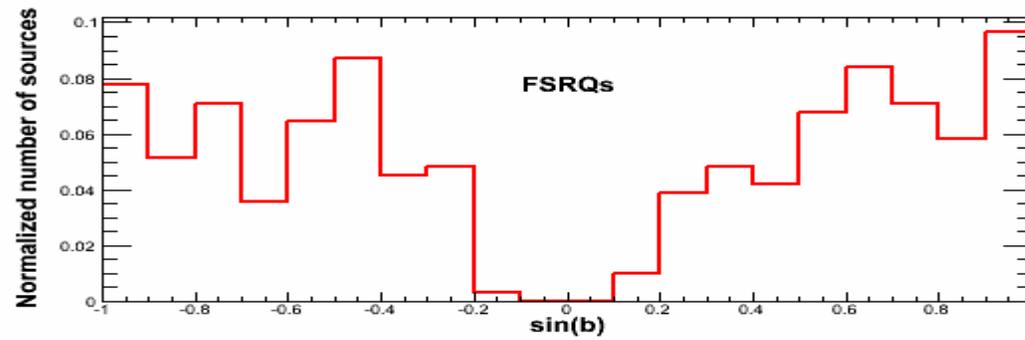
# Census



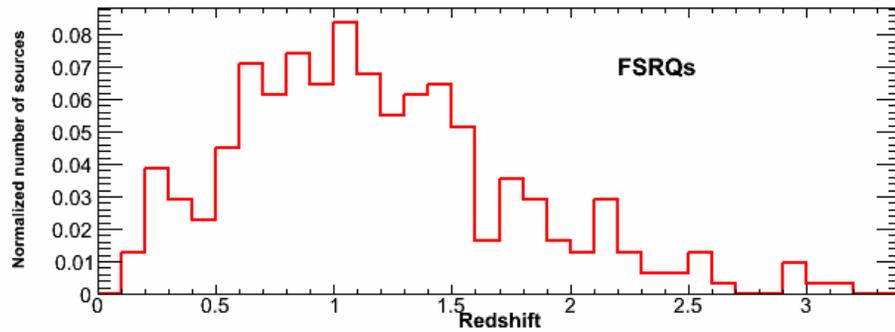
AGN type	Entire 2LAC	2LAC Clean Sample <sup>a</sup>	Low-lat sample
<b>All</b>	<b>1017</b>	<b>886</b>	<b>104</b>
<b>FSRQ</b>	<b>360</b>	<b>310</b>	<b>19</b>
...LSP	246	221	7
...ISP	4	3	2
...HSP	2	0	0
...no classification	108	86	10
<b>BL Lac</b>	<b>423</b>	<b>395</b>	<b>16</b>
...LSP	65	61	3
...ISP	82	81	3
...HSP	174	160	5
...no classification	102	93	5
<b>Blazar of Unknown type</b>	<b>204</b>	<b>157</b>	<b>67</b>
...LSP	24	19	10
...ISP	13	11	3
...HSP	65	53	13
...no classification	102	74	41
<b>Other AGN</b>	<b>30</b>	<b>24</b> *	<b>2</b>

\* 8 misaligned AGNs, 4 NLS1s, 10 AGNs of other types, 2 starburst galaxies  
 45 (out of 599) 1 LAC clean sample sources are missing in 2LAC  
 3C 78, 3C 111, 3C 120 out      Fornax A, Cen B in

# Galactic latitude distributions



# Redshift distributions

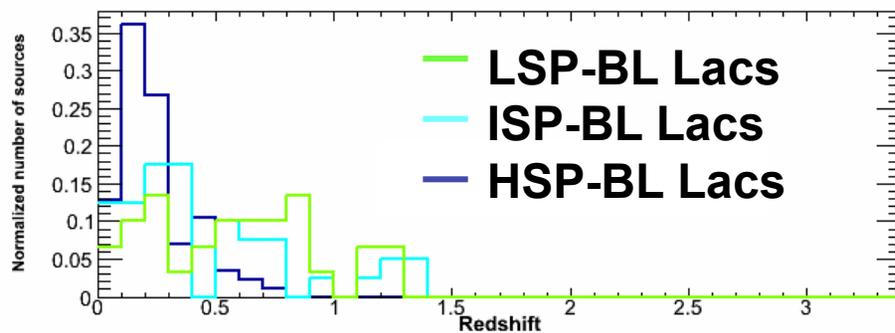
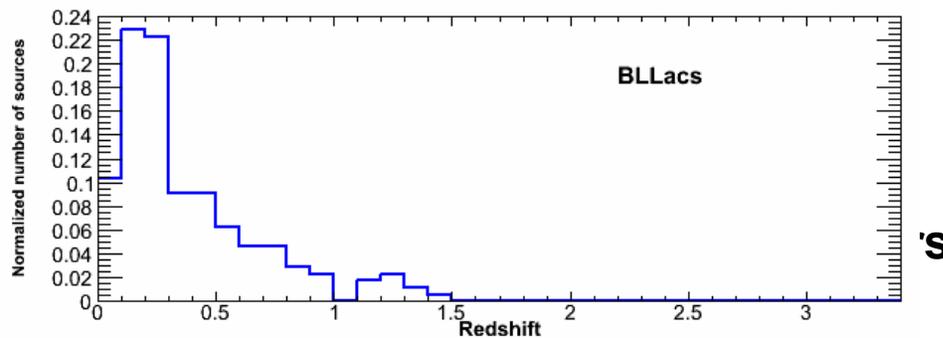


Distributions similar to 1LAC

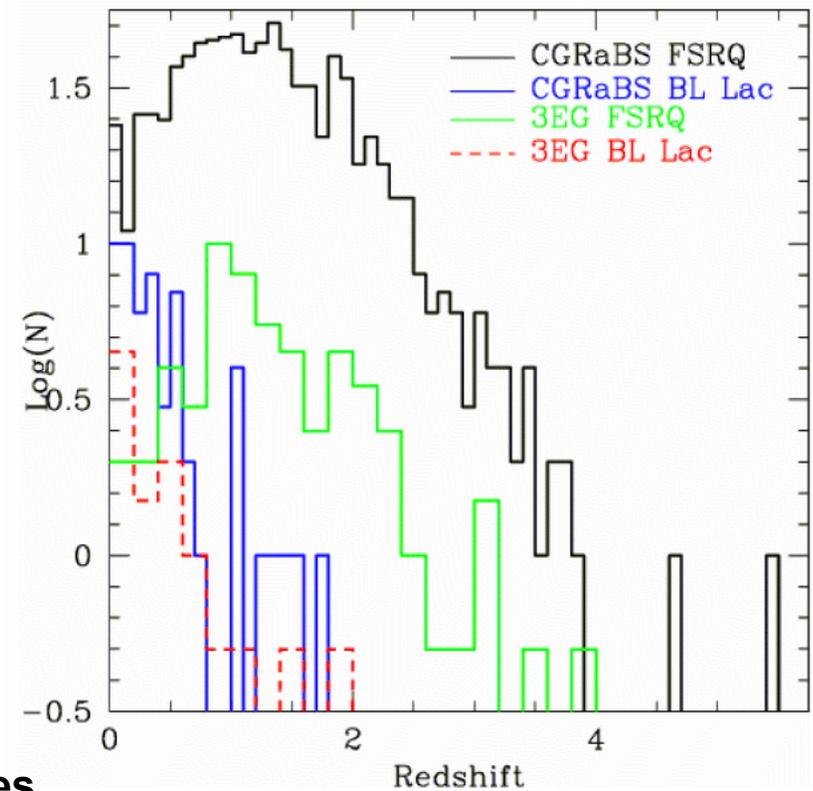
$z_{\max}$  for FSRQs: 3.1

BAT: 40% of FSRQs with  $z > 2$

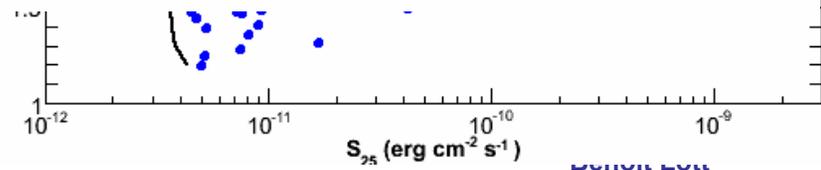
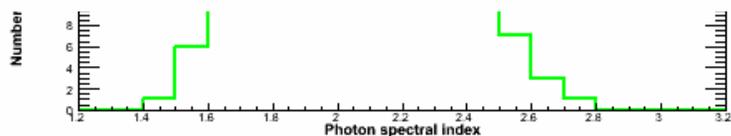
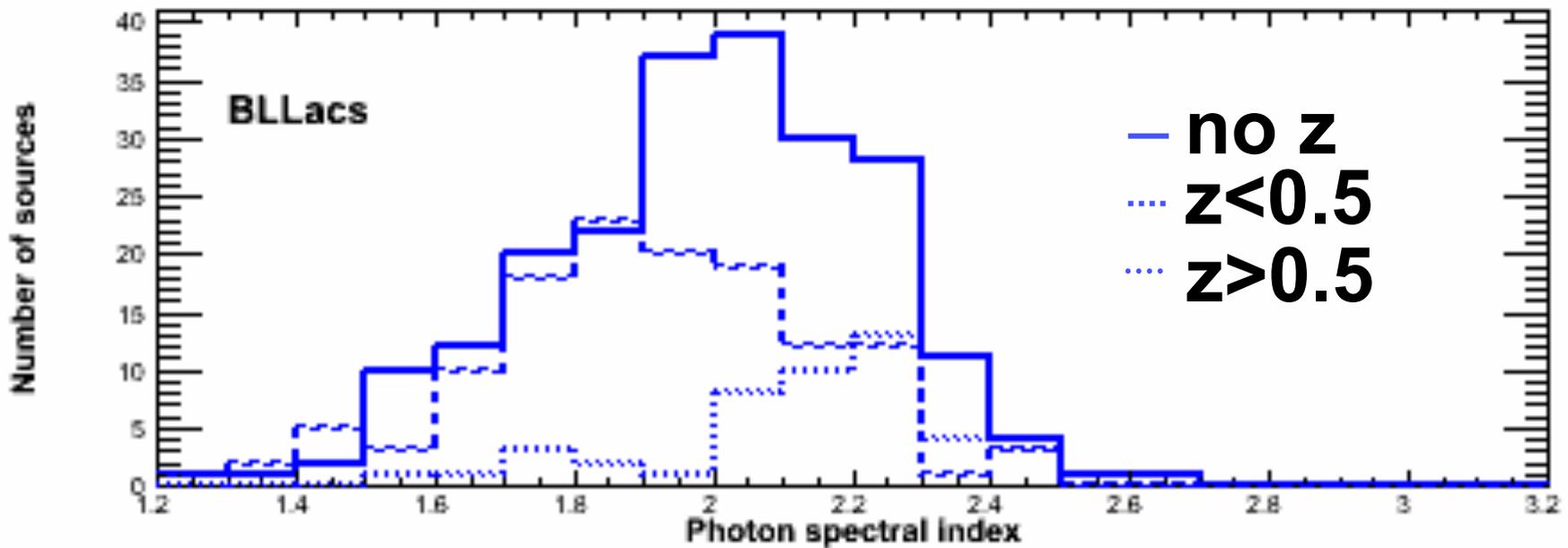
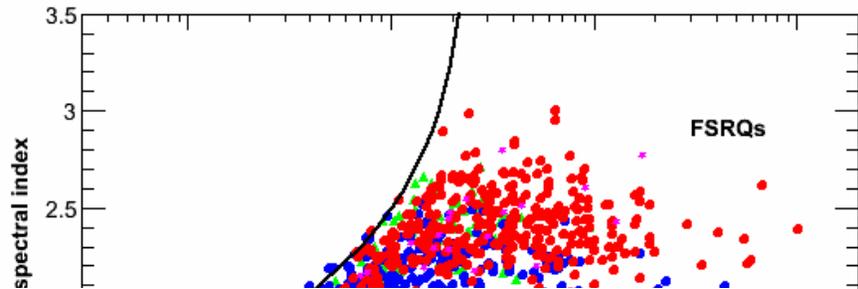
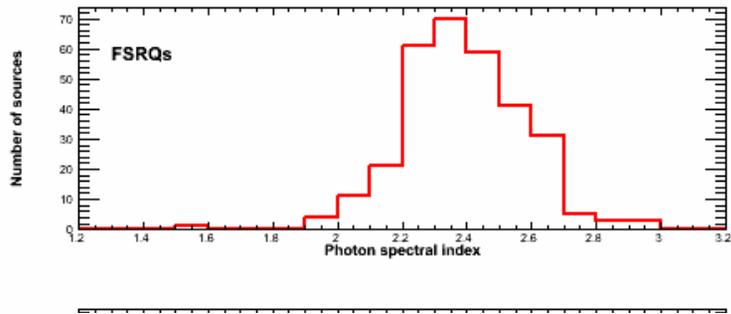
50 BZCat FSRQs with  $z > 2$



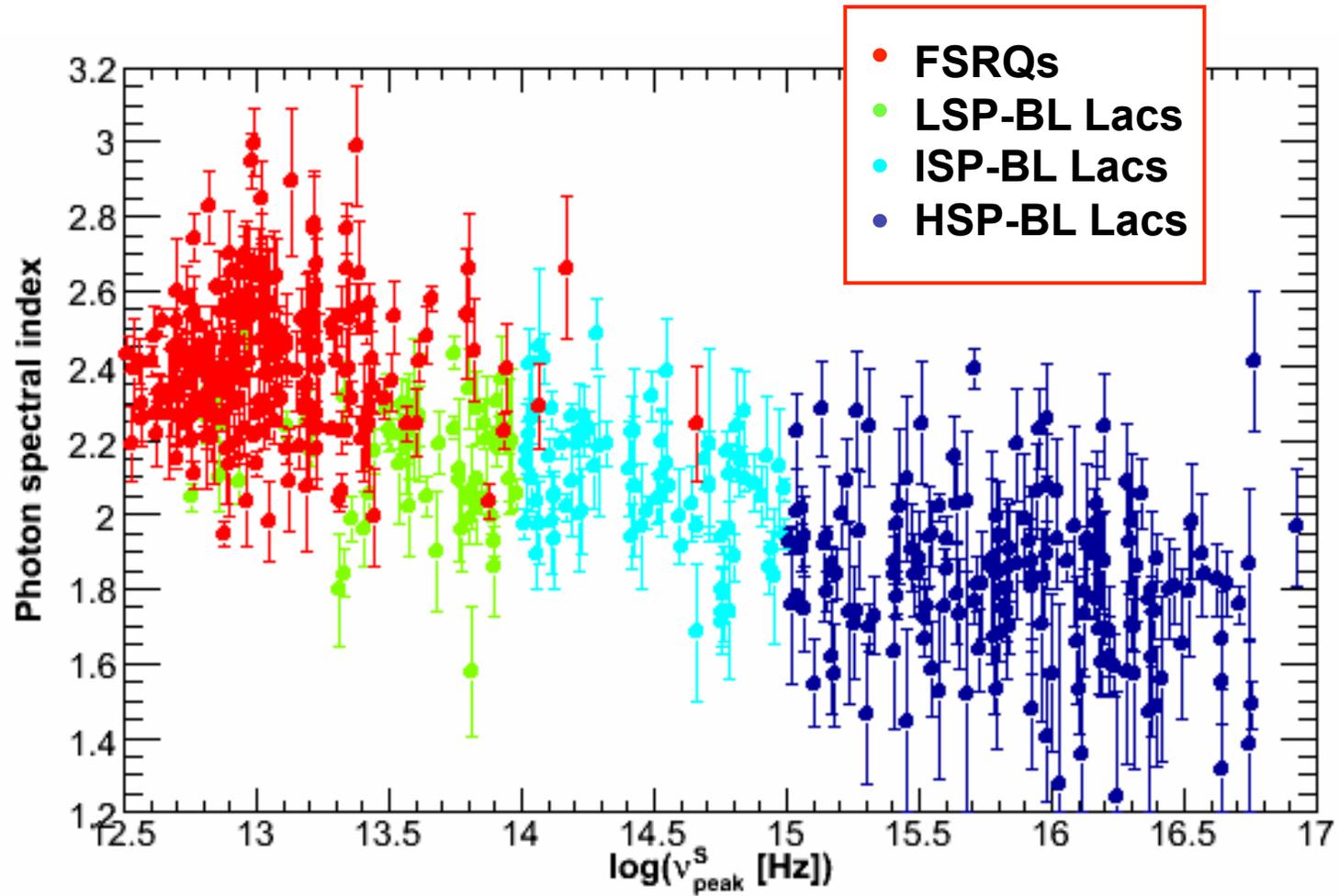
~50% of BL Lacs without redshift for all subclasses



# Photon index – Flux distributions



# $\nu_{\text{peak}}$ vs. photon index

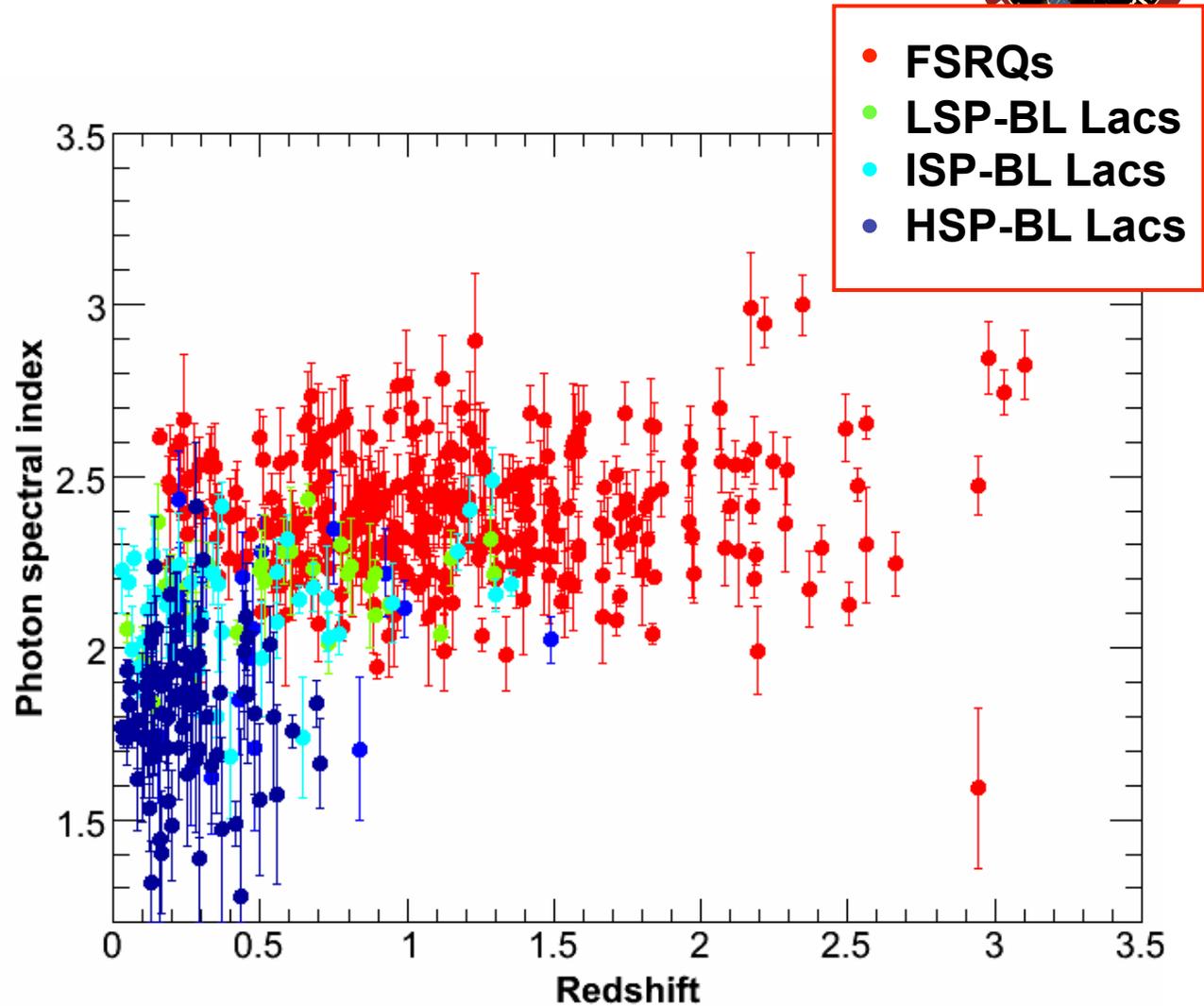


# Redshift vs. photon index



No evolution of photon index vs  $z$  for FSRQs

Strong evolution for BLLacs but just due to different subclasses (LSP, ISP, HSP) having different redshift distributions

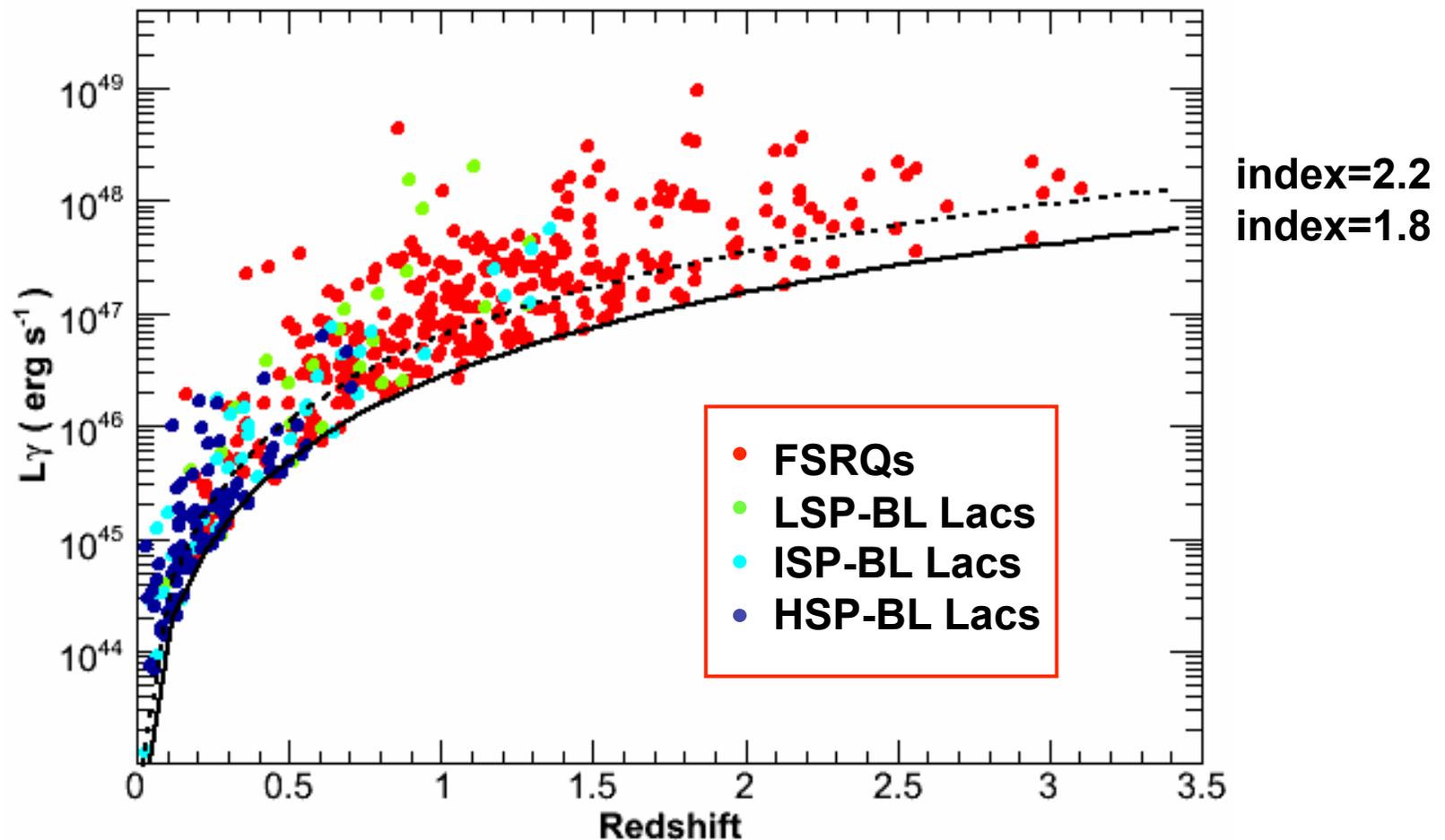


# Redshift vs. Luminosity

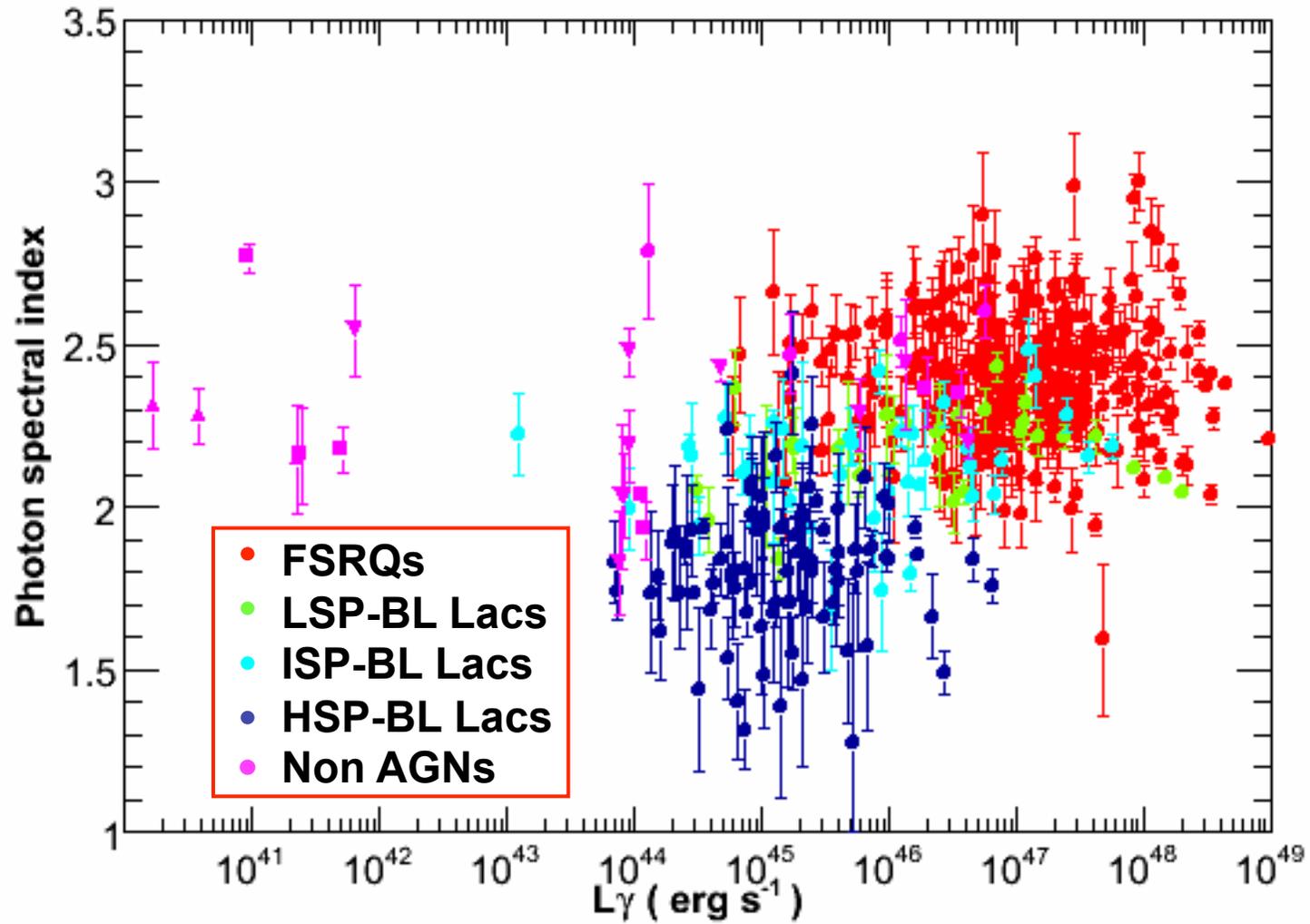


$$L_{\gamma} = 4\pi d_L^2 \frac{S(E_1, E_2)}{(1+z)^{2-\Gamma}}$$

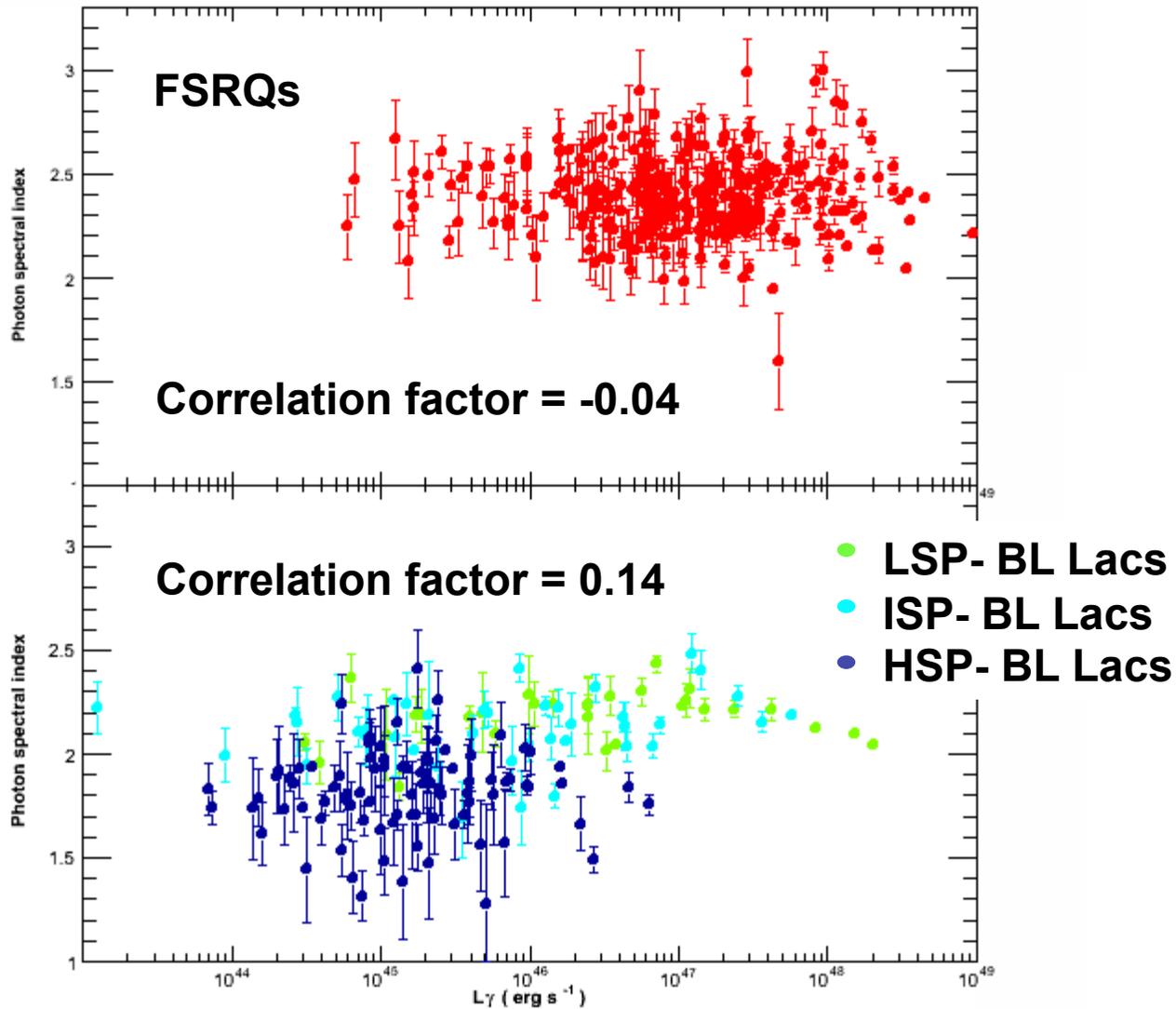
$d_L$ : luminosity distance  
 $S(E_1, E_2)$ : energy flux between  
 $E_1$  (100 MeV) and  $E_2$  (100 GeV)



# Photon index vs luminosity



# Photon index vs luminosity



## GeV-TeV Connection



39/45 TeV AGNs are in the 2LAC  
(34 in clean sample)  
~ only 13 show display significant  
variability in the Fermi-LAT band

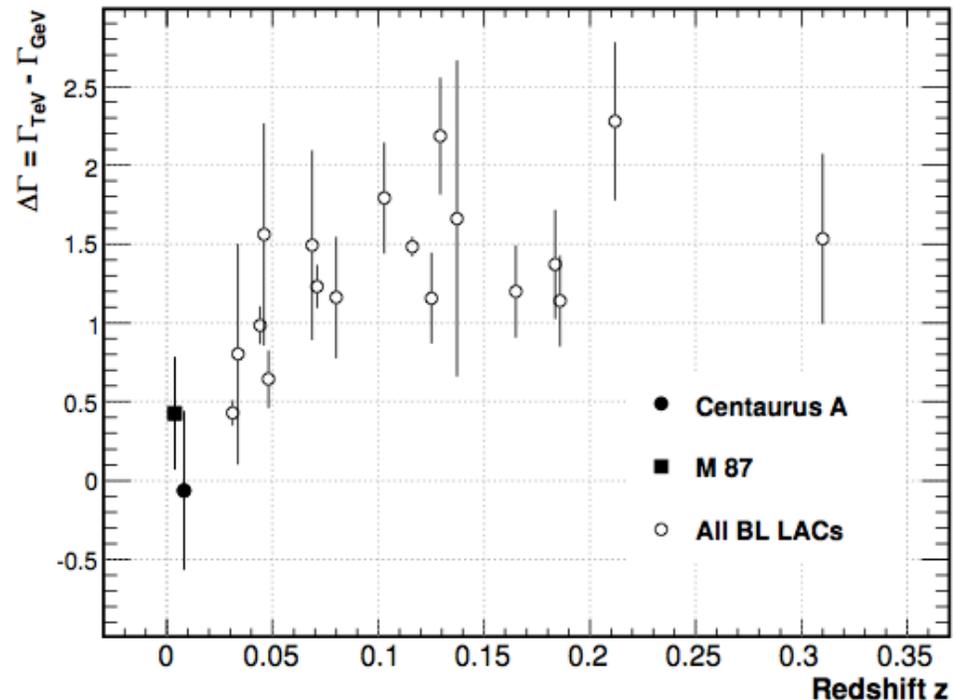
22 TeV AGNs discovered since the  
launch of Fermi  
Fermi implicated in the detection of  
9 objects

26 AGNs are well fitted with simple  
power law in the LAT band

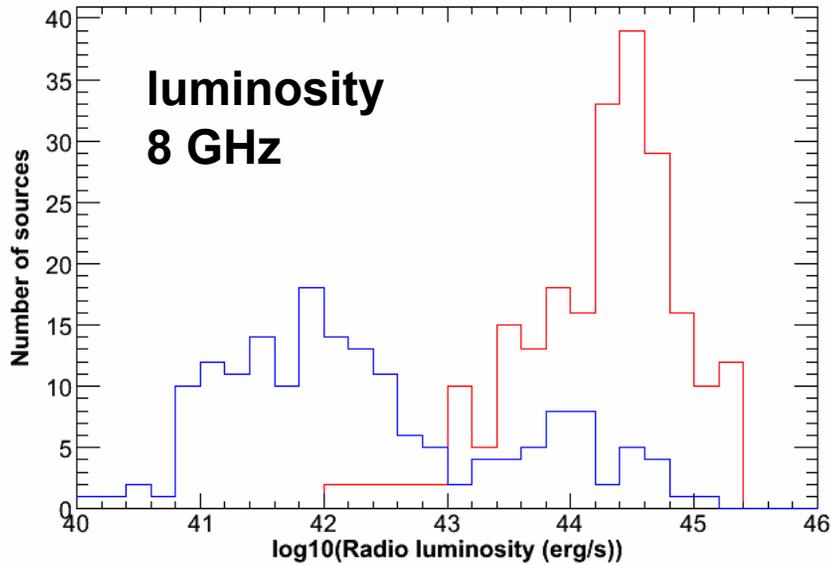
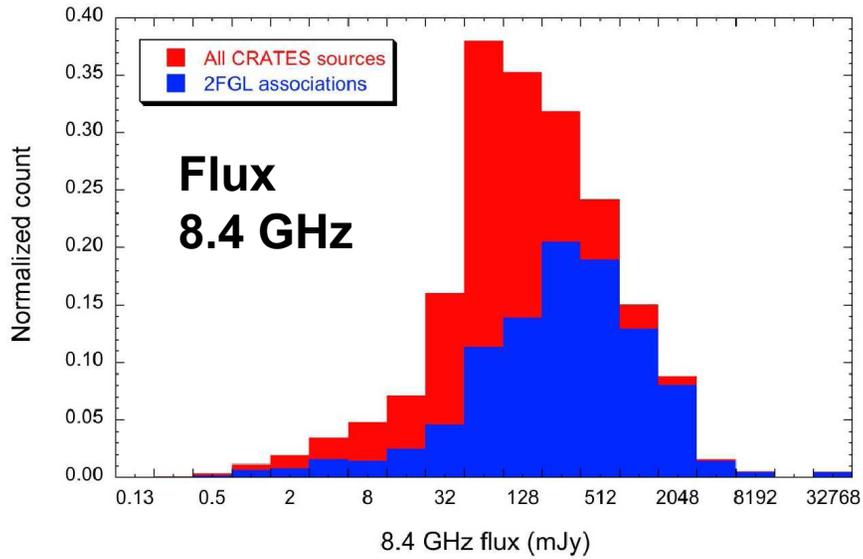
- HSPs: 17
- ISPs: 2
- LSPs: 2
- unknown type: 5

Deficit of distant sources with small  
values of  $\Delta \Gamma$

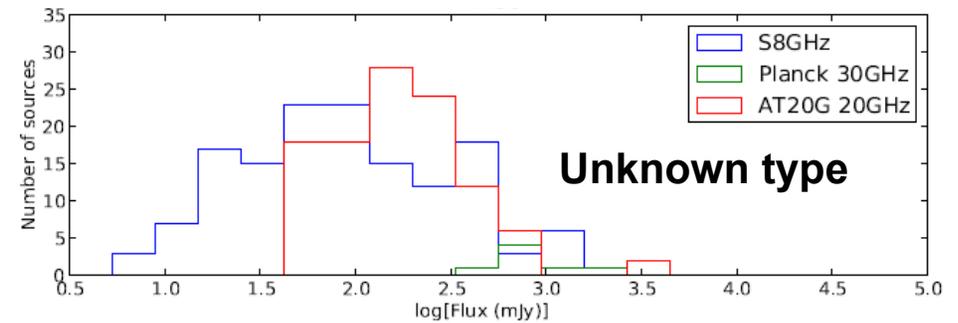
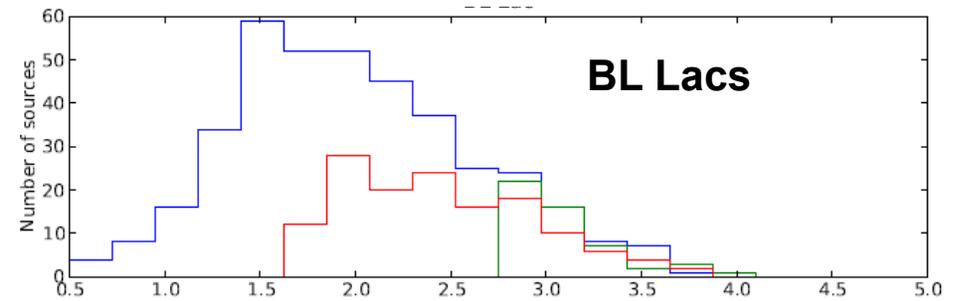
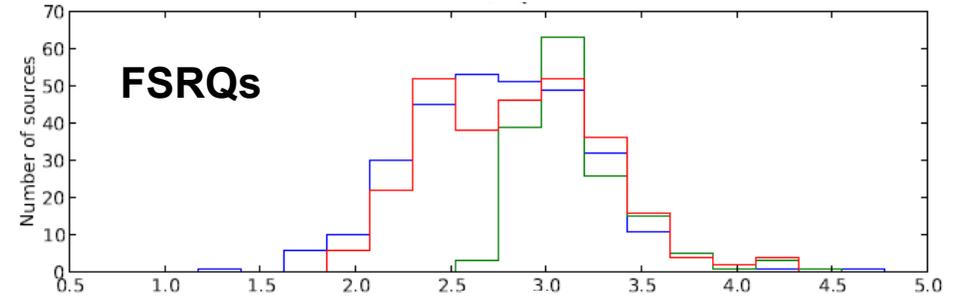
- EBL: softening of the VHE
- spectrum dependent on  $z$



# Radio properties

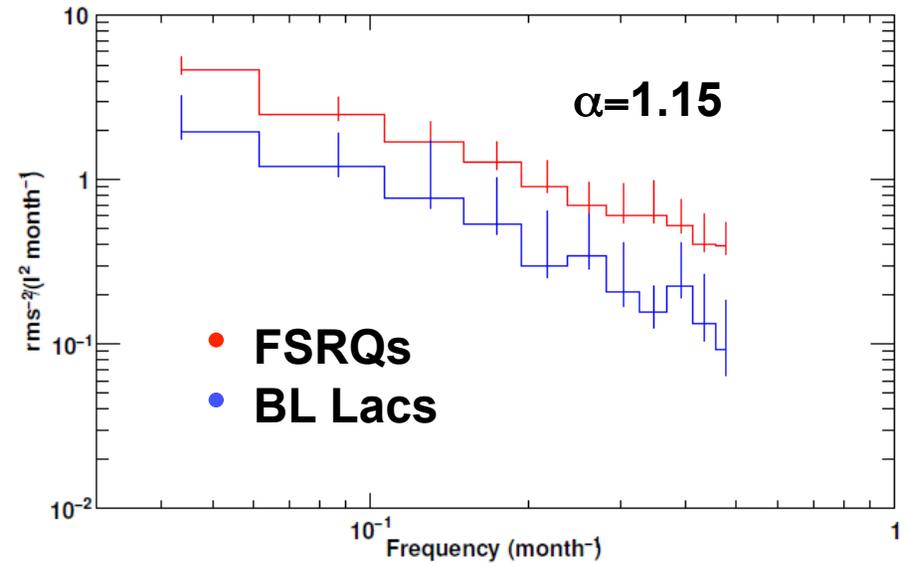
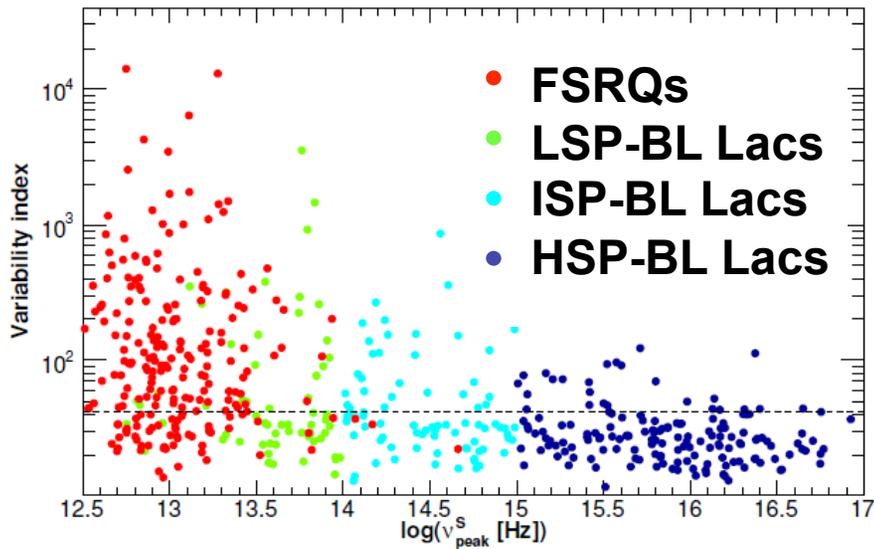
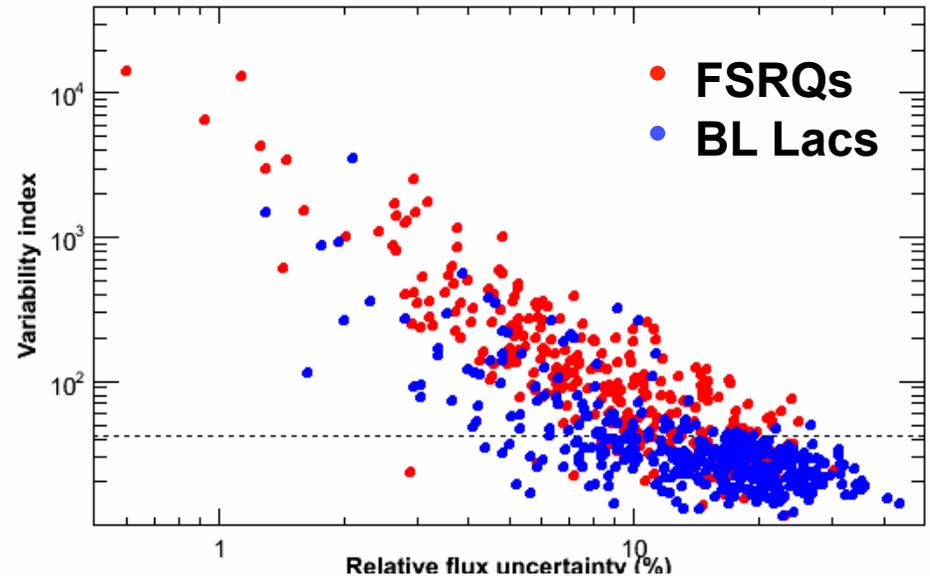
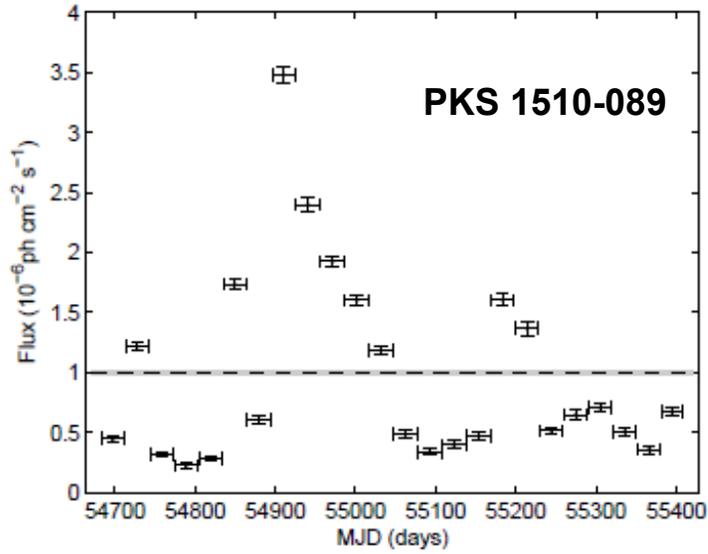


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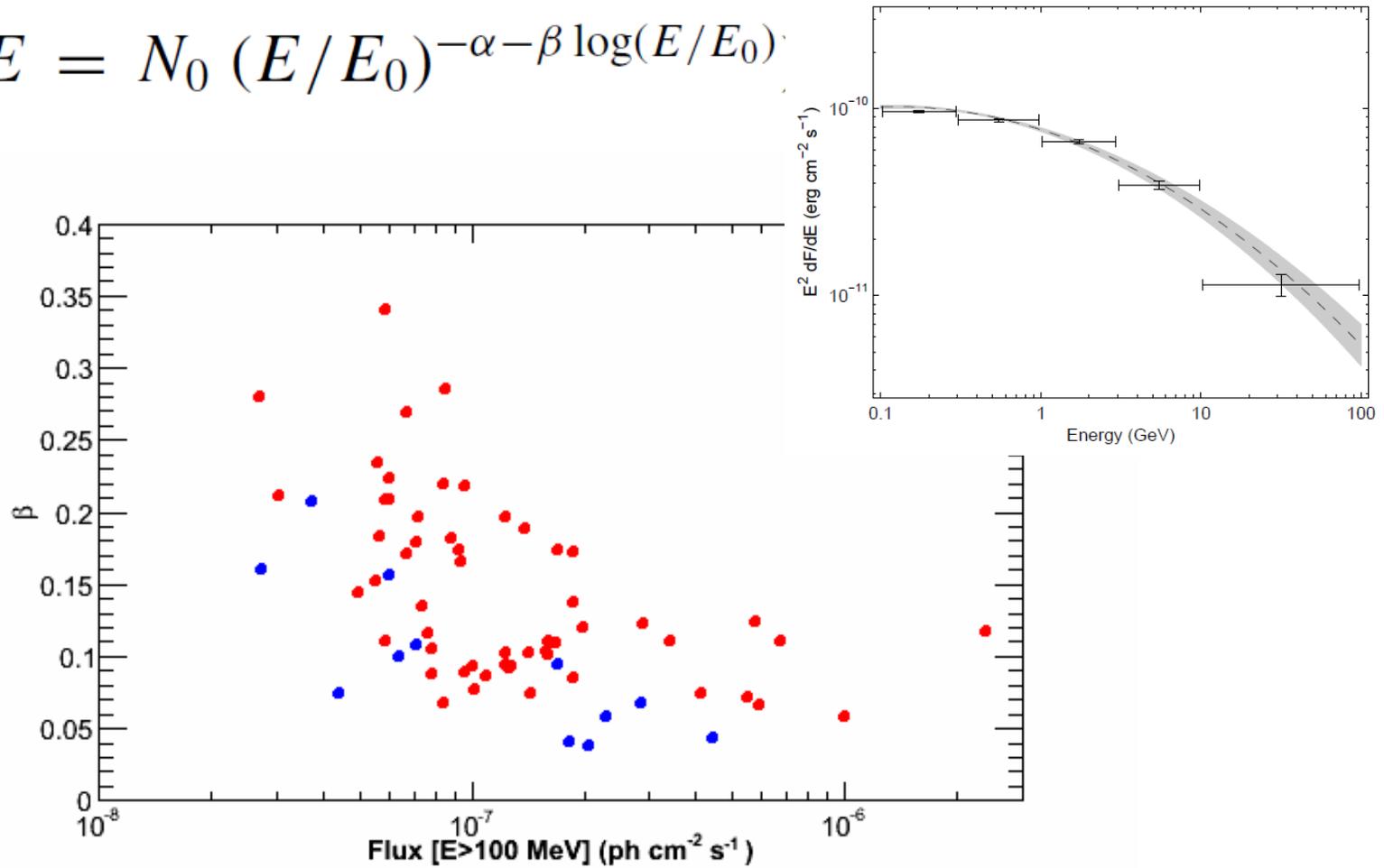
# Variability



# Spectral Curvature



$$dN/dE = N_0 (E/E_0)^{-\alpha - \beta \log(E/E_0)}$$



## 2LAC summary



- number of associated sources has increased by 52% over 1LAC
- 75% of 2FGL sources at high  $b$  are included into the 2LAC
- More than 97 % sources are blazars.
- 24 non-blazar sources in Clean Sample
  - 8 misaligned AGNs (see Paola Grandi's talk)
  - 4 NLS1s
  - 10 AGNs of other types
  - 2 starburst galaxies
- BL Lacs outnumber FSRQs (395/310)
- 55% BL Lacs lack measured redshifts
- Among BL Lacs, HSPs dominate over ISPs and LSPs (53%, 27%, 20%)
- 39/45 TeV AGNs have now been detected

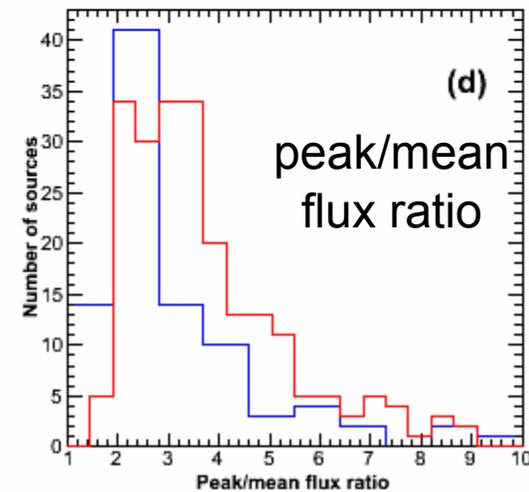
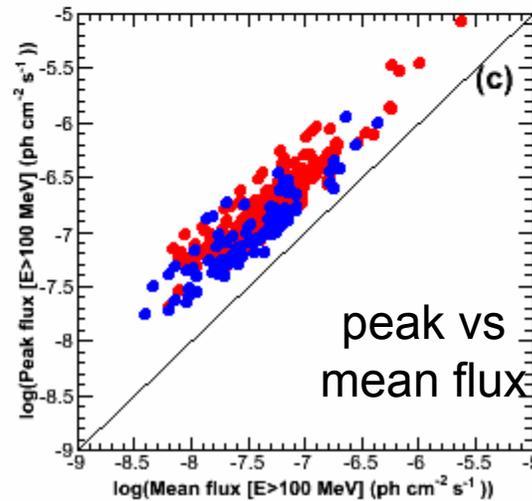
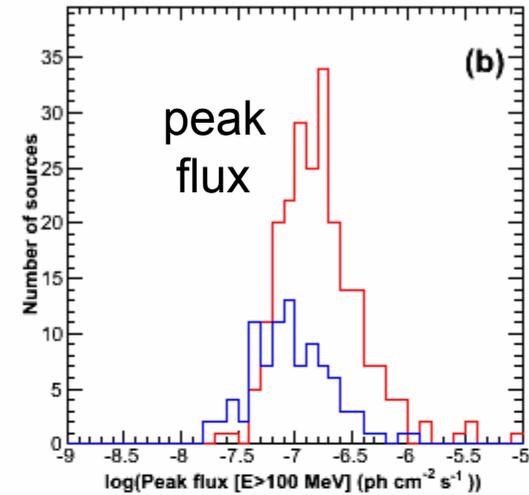
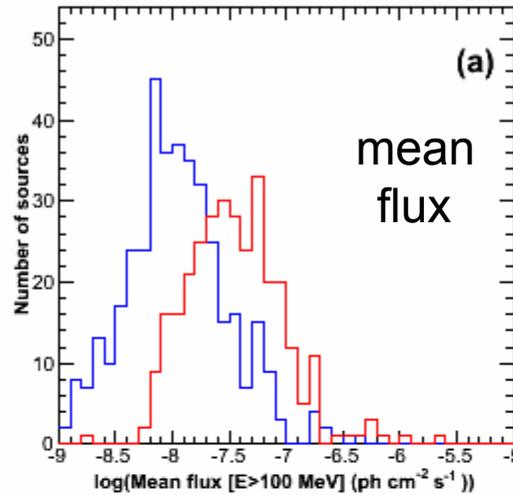
Next catalog should be based on 5 year worth of data.

# Mean/Peak Flux distributions

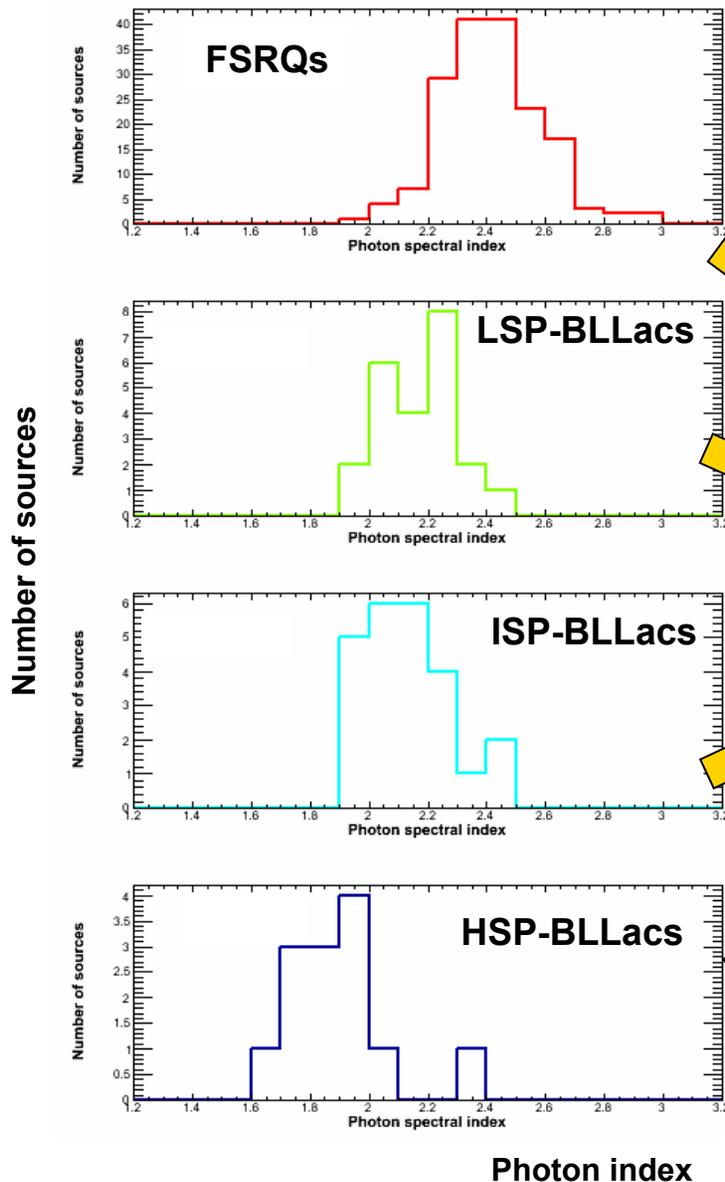


**FSRQs**  
**BLLacs**

See S. Larsson's  
talk

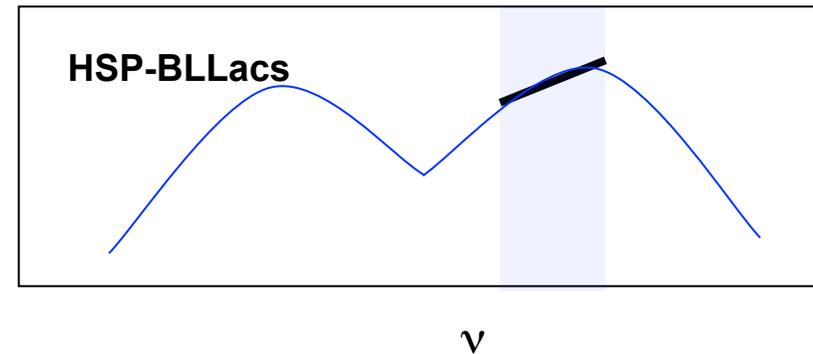


# Photon index distributions in 2LAC



Photon index

LAT range



- Strong correlation between photon index and blazar class
- Narrow distributions point to a small numbers of parameters driving the blazar SEDs